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Sugarcane Biomass Production and Renewable Energy

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1. Introduction

Bio-fuel production is rooting in Uganda amidst problems of malnutrition and looming food insecurity “in [1,2]”. The use of food for energy is a Worldwide concern as competition for resources between bio-fuel feedstocks and food crop production is inevitable. This is especially true for the category of primary feedstocks that double as food crops. Controversy surrounds the sustainability of bio-fuels as a source of energy in Uganda.

Given the above circumstances, adequate studies are required to determine the amount of feedstock or energy the agricultural sector can sustainably provide, the adequacy of land resources of Uganda to produce the quantity of biomass needed to meet demands for food, feed, and energy provision. Sugarcane is one of the major bio-fuel feed-stocks grown in Uganda.

Growth in sugarcane cultivation in Uganda is driven by the increased demand for sugar and related by-products. Annual sugar consumption in Uganda is estimated at 9 kg per capita with a predicted per capita annual consumption increase by 1 % over the next 15 years “in [3]”.

This growth has resulted in increased demand for land to produce staple foods for households and thus encroaching on fragile ecosystems like wetlands, forests and shallow stoney hills and, a threat to food security “in [4]”. The situation is likely to worsen with the advent of technology advancements in the conversion of biomass into various forms of energy like electricity and biofuels. A development that has attracted government and investors into the development of policies “in [5, 6]” that will support the promotion of bio-fuels in Uganda “in [7]”.

Competition for land resources and conflicts in land use is imminent with the advent of developments in the use of agricultural crop resources as feedstocks for renewable energy

production. Sugarcane is one such crop for which production is linked to various issues including the sustainability of households in relation to food availability, income and environmental integrity. The plans for government to diversify on alternative sources of energy with focus on biofuels and electricity generation has aggravated the situation. This chapter aims at demonstrating how sugarcane biomass can sustainably be produced to support fuel and electrical energy demands while conserving the environment and ensuring increased household income and food security.

This study was conducted with a major objective of assessing sustainable production of bio-fuels and electricity from sugarcane biomass in the frame of household poverty alleviation, food security and environmental integrity.

2. Research methods

The assessment of sugarcane production potential is done for the whole country. The rest of the studies were done at the Sugar estate and the outgrower farmers.

2.1. Assessment of sugarcane production potential

The overall suitability assessment involved the use of the partial suitability maps of temperature, rainfall and soil productivity ratings (Figures 1 and 2). An overlay of the three maps gave suitability ratings for sugarcane bio-fuel feedstock.

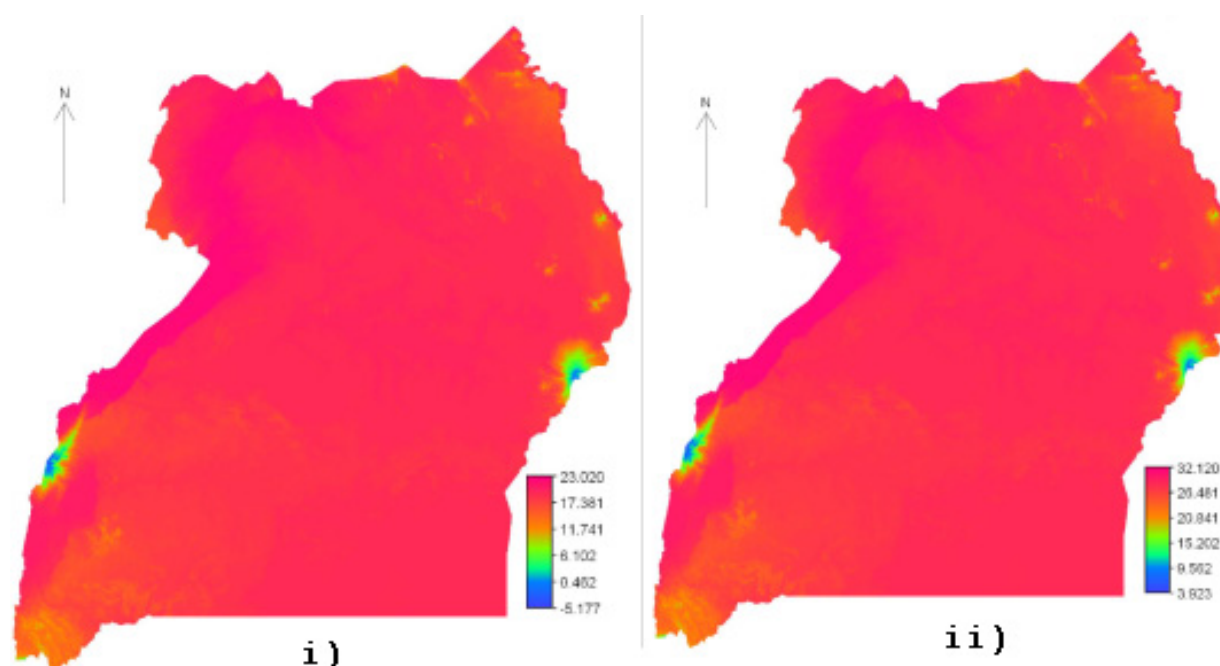


Figure 1. i) Minimum temperatures and maximum temperatures ii) “ in [8] ”.

Subtraction of gazetted areas, wetlands and water bodies produced final suitability maps and tables presented in the results. Steep areas have not been excluded since they are associated with highlands which are densely populated areas. It is hoped that soil

conservation practices will be practiced where such areas are considered for production of sugarcane feedstock. Urban areas, though expanding, are negligible and have not been considered in the calculations.

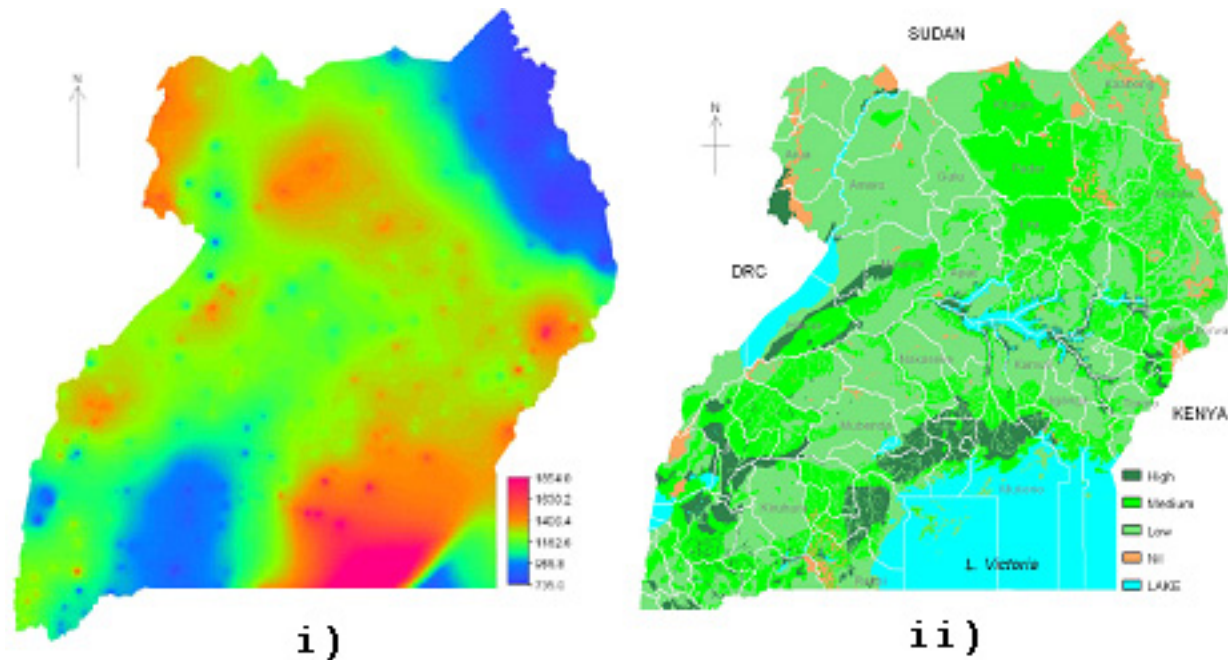


Figure 2. i) Mean annual rainfall “ in [8] ”; ii) Soil productivity ratings “ in [9] ”.

The suitability of the land resource quality for sugarcane was based on sets of values which indicate how well each cane requirement is satisfied by each land quality say: mean annual rainfall, minimum and maximum temperatures and soil productivity. The four suitability classes (rating), assessed in terms of reduced yields, and were defined according to “ in [10] ”. Potential land-use conflict visualization also gives an indication of land available for the production of sugarcane bio-fuel feedstocks. Conflict visualization for food versus sugarcane was done by an overlay of suitability maps of maize with sugarcane. Land-use conflict with gazetted areas was assessed by overlaying gazetted area maps with sugarcane suitability map.

2.2. Sustaining sugarcane biomass productivity

The total biomass production of five commercial sugarcane varieties grown on the estate across all crop cycles (plant and three ratoons) was developed.

The data on cane yield and cane productivity of plant and ratoon crops between 1995-1996 and 2009-2010 were collected from annual reports and compared to experimental data. The total bio-mass (cane, trash and tops) production in plant and two ratoons were recorded at harvest age i.e. 18 and 17 months for plant and ratoon crops respectively. Data was collected from three locations of plot size 54 m² (4 rows of 10m length). Nutrient status of crop residues on oven dry basis was adopted as suggested by “ see [11] ” for calculation of nutrient return to the soil and nutrients available to succeeding crop.

A replicated trial with four replications was established during 2009-2010 with different levels of chemical fertilizers and factory by-products (filter mud and boiler ash) to test their influence on cane and sugar yields.

Semi-commercial trials were established on the estate to study the influence of green manuring with sunn hemp against no green manured blocks (control), aggressive tillage against reduced tillage, and intercropping with legumes on cane yield and juice quality parameters.

Field studies were conducted during 2002-2004 and 2007-2009 to evaluate the influence of different levels of Nitrogen (N), Phosphorus (P), Potassium (K) and sulphur (S) on cane yield and juice quality of plant crop of sugarcane.

The cane yield data on green cane vs burnt cane harvesting systems, and aggressive vs reduced tillage operations were collected and analysed for biomass yield.

2.3. Assessment of potential biofuel productivity and cane biomass electricity generation

Ethanol yield estimates from sugarcane is based on yield per ton of sugarcane. In addition, the production of bagasse from the cane stalk available for electricity generation were collected and analysed as per the following bagasse-steam-electrical power norms at Kakira sugar estate:

- i. Bagasse production is 40 % of sugarcane production
- ii. Moisture % in bagasse is 50%
- iii. 1.0 ton of bagasse produces 2.0 tons of steam
- iv. 5.0 tons of steam produces 1.0 Mwh electrical power

Therefore 2.5 tons of bagasse produces 5.0 tons of steam which will generate 1.0 Mwh electrical power. The electric power used in Kakira is hence generated from a renewable biomass energy source.

In 2005, Kakira had two 20 bar steam-driven turbo-generators (3 MW + 1.5 MW) in addition to 5 diesel standby generators. Thereafter, two new boilers of 50 tonnes per hour steam capacity at 45 bar-gauge pressure, with all necessary ancillaries such as an ash handling system, a feed water system and air pollution controls (such as wet scrubbers and a 40m 30 high chimney) were installed

2.4. Contribution to household income and food security

Indicative economic assessments included the use of gross sales for the raw material (farm gate) and ethanol. Annualized sugarcane net sales were compared to household annual expenditures to allow assessment of cane contribution to household income. Integration of commodity prices gives insight on the potential contribution of bio-fuels to household poverty alleviation and overall development of rural areas.

3. Results

3.1. Suitability

The agro-ecological settings favor the growing of sugarcane with a potential 10,212,757 ha (49.6%) at a marginal level of production with 2,558,698 ha (12.4%) land area potentially not suitable for cane production. Although the current production is far below the potential production “in [12]”, the related cane production is 908,935,330 and 60,769,069 tons respectively. It is also evident that there is possibility of increasing production through expansion of land area under sugarcane.

1. Suitability of sugarcane production and conflict visualization between food crops and gazetted areas in Uganda

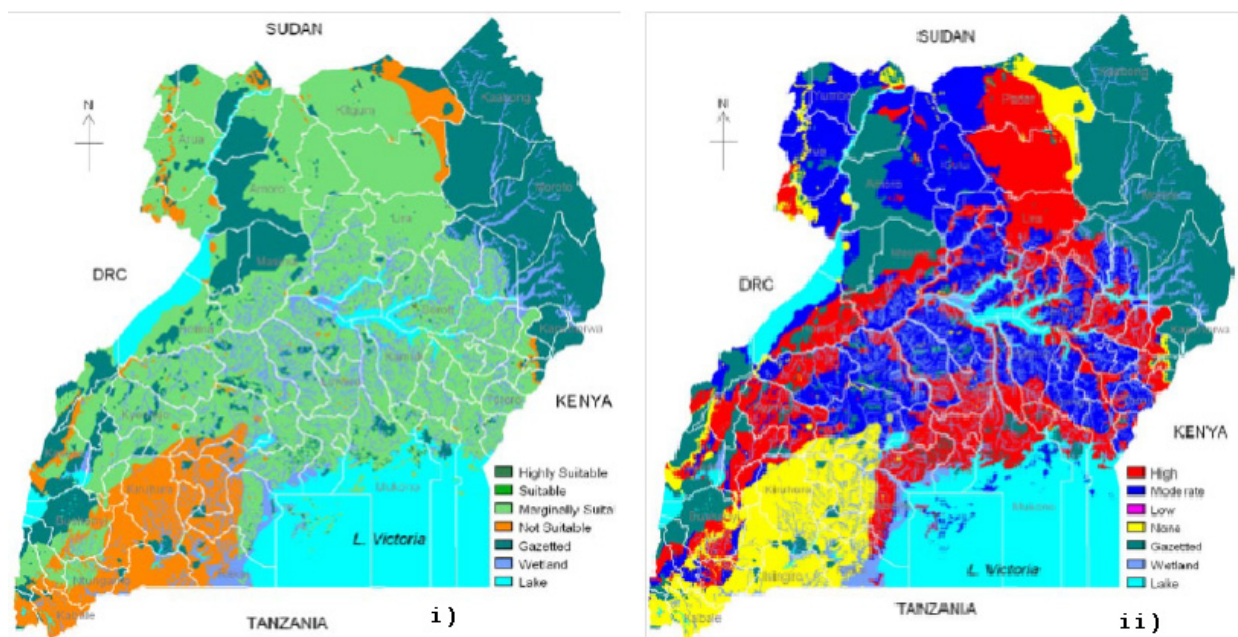


Figure 3. Sugar cane suitability ratings (i) and conflict visualization between food crops and gazetted areas

The marginal productivity of cane in Uganda is a function of Rainfall amount and the atmospheric temperature. Nevertheless the average optimum yields (89 ton / ha) at marginal level of productivity are comparable to yields of 85 ton / ha in a commercialized production in Brazil “in [13]”.

Expanding acreage under sugarcane is likely to increase pressure on gazetted biodiversity rich areas including wetlands with consequent potential loss of bio-diversity.

Sugarcane and maize (food crop) have similar ecological requirements, presenting a situation of high potential land-use conflict as 49.6 % of arable land can be grown with both sugarcane and food crops (figure 3 i). Figure 3 ii), shows 14 % of the land where sugarcane has potential conflict with gazetted areas of which 4.3 % has potential conflict with forest reserves.

Sugarcane, given its energy balance advantage, is likely to be beneficial if promoted as bio-fuel feedstock as this is likely to increase sugarcane prices to the benefit of the small scale farmer.

3.2. Agronomy

The beneficial effects of integrated agronomic practices like reduced tillage operations, balanced fertilization; organic recycling of mill by-products (filter mud and boiler ash); intercropping with legumes; green manuring with sunn hemp; crop residue recycling through cane trash blanketing in ratoons by green cane harvesting to sustain soil fertility and cane productivity in monoculture sugarcane based cropping system are presented and discussed. Partitioning of dry matter between plant and ratoon crops of cane grown on the estate and Outgrowers fields were quantified and also presented in this chapter.

3.2.1. Influence of agronomic practices on cane yield and cane productivity

3.2.1.1. Green manuring

There was considerable increase in cane yield (7.92 tc/ha) and cane productivity (0.62 tc/ha/m) in plant and ratoon crops due to green manuring as compared to blocks without green manuring (Table 1).

Crop cycle	Green manuring		No green manuring		Variance	
	Yield tc/ha	Productivity tc/ha/m	Yield tc/ha	Productivity tc/ha/m	Yield tc/ha	Productivity tc/ha/m
Plant	125.3	5.9	112.2	5.2	13.1	0.8
Ratoon 1	95.3	5.8	92.4	5.0	2.8	0.8
Ratoon 2	92.4	5.0	84.6	4.7	7.8	0.3
# average	104.3	5.6	96.4	5.0	7.9	0.6

Table 1. Cane yield and cane productivity variance due to green manuring

Growing sunn hemp (*Crotalaria juncia*) during fallow period for in-situ cultivation has been a common practice to improve soil health on the estate since 2004. Sunn hemp at 50% flowering on average produces 27.4 t/ha and 5.9 t/ha of fresh and dry weights respectively. It contains 2.5% N on oven dry basis and adds about 147kg N/ha to the soil. Of this amount, 30% (44kg N/ha) is presumed to be available to the succeeding sugarcane plant crop. “[11]” reported that N available to sugarcane ranges between 30 - 60% of total N added to soils in South Africa.

3.2.1.2. Balanced fertilization

The results indicated that application of N to plant crop at 100kg /ha, phosphorus at 160kg P₂O₅ /ha, potassium at 100 K₂O /ha and sulphur at 40kg /ha significantly increased the cane yields by 23.3 tc/ha; 22.25 tc/ha; 12.07 tc/ha and 8.71 tc/ha respectively over no application of

N, P, K and S. Sugar yields were also improved due to N, P, K and S application by 2.91 ts/ha; 2.17 ts/ha; 2.88 ts/ha and 0.44 ts/ha respectively as compared to no application (Table 2).

Nutrient levels (kg/ha)	Attributes	
	Cane yield (tc/ha)	Sugar yield (ts/ha)
N levels: 0	112.68	15.69
50	124.38	17.08
100	135.98	18.60
P ₂ O ₅ levels: 0	108.70	14.51
80	120.40	16.34
160	130.95	18.01
K ₂ O levels: 0	108.06	15.58
50	124.86	17.32
100	134.13	18.46
Sulphur levels: 0	113.90	11.92
40	122.61	12.36
CD at 5%: N	10.69	1.20
P ₂ O ₅	9.80	1.18
K ₂ O	9.06	1.06
S	6.94	0.32

Table 2. Influence of N, P, K and S nutrition on cane and sugar yields

Balanced fertilizer application is very vital for crop growth. Adequate amounts of especially the major nutrients need to be supplied for proper crop growth. Excessive application of N in cane plant crop has been shown to inhibit the activity of free living N-fixing bacteria and chloride ions from Muriate of potash adversely affecting soil microbial populations “in [14]”.

3.2.1.3. Mill by-products

Millable stalk population at harvest was significantly higher due to application of filter mud and boiler ash + 100% recommended dose of fertilizers (RDF) than all other treatment combinations. However, there was no significant effect on stalk length, number of internodes and stalk weight due to different treatments. Cane and sugar yields were significantly higher by 30.2 tc/ha and 3.8 ts/ha respectively due to application of filter mud and boiler ash + 100% RDF. The data are presented in Table 3.

Cane-mill by-products (filter mud and boiler ash) do contain valuable amounts of N, P, K, Ca, and several micronutrients “in [15]”. These in addition to the inorganic fertilizers applied considerably increased cane yields as compared to treatments which received only inorganic fertilizers. In [11] it is also showed that organic wastes-including filter mud and boiler ash could be used as an alternative source of nutrients in cane cultivation.

Treatment	Yield (T/ha)	
	Cane	Sugar (Estimated)
1. 100% recommended dose of fertilizers (RDF)	131.6	16.6
2. Filter mud + Boiler ash @ 32 + 8 T/ha alone	122.1	16.2
3. 100% RDF+ Filter mud + Boiler ash @ 32 + 8 T/ha	161.7	20.4
4. 75% RDF+ Filter mud + Boiler ash @ 32 + 8 T/ha	143.8	17.5
5. 50% RDF+ Filter mud + Boiler ash @ 32 + 8 T/ha	142.1	17.3
6. 25% RDF+ Filter mud + Boiler ash @ 32 + 8 T/ha	135.0	16.6
CD @ 5%	12.3	1.9

Table 3. Influence of mill by-products on cane and sugar yields

3.2.1.4. Partitioning of bio-mass

Among the crop cycles, plant crop recorded higher bio-mass production than succeeding ratoons. The production of crop residues were also higher (50.7 t/ha) in plant crop than 1st (45.7 t/ha and 2nd (36.6 t/ha) ratoons. The data are presented in the Table 4 below.

Crop cycle	Cane weight (Tc/ha)	Tops weight (T/ha)	Trash weight (T/ha)	Total bio-mass (T/ha)	Tops + Trash weight T/ha	% over total
Plant	137.5	30.3	20.4	188.2	50.7	27.0
Ratoon 1	124.9	26.8	18.9	170.59	45.7	27.0
Ratoon 2	107.5	19.7	16.8	144.02	36.6	25.4
# average	123.3	Fresh: 25.6 Dry: 9.0	Fresh: 18.7 Dry: 16.9	- -	Fresh: 44.3 Dry: 25.8	26.4

Table 4. Crop-wise partitioning of bio-mass

Results indicate that on average, 25.8 tons of dry matter (cane trash and tops) is produced from each crop cycle at harvest. In burnt cane harvesting system, all this dry matter is lost unlike in green cane harvesting. This explains the gradual decline in cane yield in such harvesting systems. The decline is presumed to be due to deteriorating organic matter and other physical and chemical properties of the soil “ in [11] ” .

After decomposition of cane trash, 139kg N, 59kg P₂O₅, 745kg K₂O, 41kg Ca, 46kg Mg and 34kg S /ha were added to the soils and these added nutrients would be available to the succeeding crop at 30% of the total nutrients “ in [11] ” . The nutrient concentration of crop residues (trash + tops) were taken into account for computing nutrient additions to the soil and their availability to the succeeding ratoon crops and the data are presented in Table 5.

Nutrient status of crop residues (%)	Total dry matter (T/ha)	Total nutrients	
		Added to soil (kg/ha)	Available to crops @ 30% (kg/ha)
N : 0.54	25.8	139	42
P ₂ O ₅ : 0.23	25.8	59	18
K ₂ O : 2.89	25.8	745	223
Ca : 0.16	25.8	41	12
Mg : 0.18	25.8	46	14
S : 0.13	25.8	34	10

** Adopted from [11]

Table 5. Nutrient status of crop residues and their availability to the succeeding crops

3.3. Renewable energy potential

3.3.1. Ethanol productivity

Sugarcane, given its energy balance advantage, is likely to be beneficial if promoted as bio-fuel feedstock as this is likely to increase sugarcane prices to the benefit of the small scale farmer.

Promoting sugarcane as a feedstock for ethanol is likely to improve rural livelihood and also minimize on forest encroachment since energy output per unit land area is very high for sugarcane.

In Brazil for example the production of sugar cane for ethanol only uses 1% of the available land and the recent increase in sugar cane production for bio-fuels is not large enough to explain the displacement of small farmers or soy production into deforested zones “ in [13] ”.

To minimize competition over land, it is advisable to grow sugarcane that has high yields with higher energy output compared to other biofuel crops. High yielding bio-fuels are preferable as they are less likely to compete over land “in [16]”.

3.3.2. Bioelectricity generation

Hydropower contributes about 90 per cent of electricity generated in Uganda with sugarcane based bagasse bioelectricity, fossil fuel and solar energy among other sources of power. Although the current generation of 800 MW “in [18] ”. has boosted industrial growth, the capacity is still lagging behind the demand that is driven by the robust growth of the economy.

The low pressure boilers of 45 bar currently generate 22 MW of which 10 MW is connected to the grid. However, Kakira sugar estate has a target of generating 50 MW of electricity with the installation of higher pressure boilers of 68 bar in 2013. This target can be surpassed given the abundance of the bagasse (Table 6 and 7).

Particulars	Plant	Ratoon 1	Ratoon 2	Ratoon 3	Total/ average
Cane harvest area (ha)	1,461.1	1,541.7	1,535.2	392.8	4,930.8
Total cane supply (tons)	155,207.3	162,132.3	137,436.4	40,138.9	494,915.9
Average cane yield (tc/ha)	106.23	105.16	89.52	87.28	100.37
Average harvest age (months)	19.20	18.15	17.98	16.50	17.96
Cane productivity (tc/ha/m)	5.53	5.79	4.97	5.29	5.40
Bagasse production /ha	42.49	42.06	35.80	34.90	40.14
Steam generation (tons /ha)	84.98	84.12	71.60	69.80	80.28
Electric power generation (Mwh/ha)	17.00	16.82	14.32	13.96	16.05

*This electric power generation is calculated based on using low pressure boilers of 45 bar at Kakira estate

Table 6. Mean estate cane production/productivity, electrical generation* norms (2008 – 2012)

Particulars	Plant	Ratoon 1	Ratoon 2	Ratoon 3	Total/ average
Cane harvest area (ha)	3,429.3	3,206.9	2,334.7	1,431.3	10,402.2
Total cane supply (tons)	320,100.20	290,073.29	188,274.65	113,837.25	912,285.49
Average cane yield (tc/ha)	93.34	90.45	80.64	79.53	87.70
Average harvest age (months)	18.50	17.50	18.00	16.00	17.50
Cane productivity (tc/ha/m)	5.05	5.17	4.48	4.97	5.01
Bagasse production /ha	37.30	36.18	32.25	31.81	35.08
Steam generation (tons /ha)	74.60	72.36	64.50	63.62	70.16
Electric power generation (Mwh/ha)	14.90	14.50	12.90	12.70	14.00

*This electric power generation is calculated based on using low pressure boilers of 45 bar at Kakira estate

Tc = Tons of cane

Table 7. Mean outgrowers cane production/productivity, electrical generation* norms (mean for 2008 – 2012)

Putting into consideration the productivity norms at Kakira estate and outgrowers (Table 8), with a potential of producing 908.9 m tons of sugarcane, Uganda has a potential of producing bio-electricity that surpasses the nation's demand by far. Much of this electrical power can be exported to the region, greatly expanding on Uganda's export base.

Particulars	Plant	Ratoon 1	Ratoon 2	Ratoon 3	Total/ average
Cane harvest area (ha)	4,890.4	4,748.6	3,869.9	1,824.1	15,333.0
Total cane supply (tons)	475,307.50	452,205.60	325,711.05	153,976.15	1,407,200.4
Average cane yield (tc/ha)	97.19	95.22	84.17	84.41	91.78
Average harvest age (months)	18.75	17.75	18.00	16.00	17.65
Cane productivity (tc/ha/m)	5.18	5.36	4.67	5.27	5.20
Bagasse production /ha	38.88	38.09	33.67	33.76	36.71
Steam generation (tons /ha)	77.76	76.18	67.34	67.52	73.42
Electric power generation (Mwh/ha)	15.55	15.24	13.47	13.50	14.68

*This electric power generation is calculated based on using low pressure boilers of 45 bar at Kakira estate

Table 8. Combined (Estate + Outgrowers cane production/productivity, Electrical power generation* norms (mean for 2008 – 2012)

3.4. Household income and food security

The competition for resources between sugarcane and food crops is apparent with foreseen consequent increased food insecurity. Fifty percent of the arable land area good for food crop production is equally good for sugarcane.

A farm household that allocates all of its one hectare of land to sugarcane is expected to earn 359 \$ at high input level, 338 \$ at intermediate level and 261 \$ at low input level “ in [4] “. The 391 \$ required to purchase maize meal is well above the net margins from one ha. This shows that proceeds from one hectare cannot sustain a household of 5. It is further revealed that maize produced from 0.63 ha can sustain a household nutritionally; however considering the annual household expenditure (760.8 \$; “in [17] ”), about three hectares of land under sugarcane are required at low input level to support a household “ in [4]”.

However, this study reveals that sugarcane sales accrued from ethanol under a scenario of a flourishing bio-fuel industry is associated with increased income that is likely to support households (Table 9). An ethanol gross sale per person per day is 1.6 dollars; an indication that the cultivation of sugarcane based biofuel is likely to contribute to alleviation of household poverty. A trickle-down effect on household income is expected from a foreseen expansion of bagasse-based electricity generation beyond the estate into the national electricity grid.

Production / year		Gross sales			Conflict		
Cane production	Billion	Farm	Ethanol	Capita	Food	Gazetted	Forest
ton	litres	/ha/year			%		
908.9 m	75.4	1869	22161	1.6	50.0	14.0	4.3
Sugarcane= USD 21/ton: projected population of 33 m in 2009 is used							

Table 9. Sugarcane productivity, sales and potential land-use conflict

4. Further research

The expansion of cane production is largely driven by market forces oblivious to the detrimental impact the industry is likely to have on food, livelihood security and the status of biodiversity. In addition to lack of appropriate policies to support the small-scale cane farmer, the policies are largely sectoral with no linkages with other relevant policies. Information is required to support the sustainable development of the cane industry with minimal negative impact on food and livelihood security and the status of biodiversity.

5. Relevant questions to explore among others include

Can food crop productivity be improved in the context of a sugarcane-based farming system?

Can the understanding of the dimensions of food and livelihood security in sugarcane-based farming systems inform the synergistic development and review of relevant policies in the food, agriculture, health, energy, trade and environment sectors? What are the social impacts of the industry in light of the various agro-ecological zones of the country? What is the gender based livelihood strategies with special emphasis on labor exploitations- child labor etc?

What do people consider as possible options for improving food and livelihood security in a sugarcane-based farming system? Do these options differ between different actors (local women and men, NGOs and government)? How do families cope with food inadequacy, inaccessibility and malnutrition?

Can the study inform the carbon credit market initiative for farming systems in Uganda through the climate smart agriculture concept? Are the proposed assessment tools appropriate for Ugandan situations and the cane-based systems in particular?

6. Conclusion

Driven by the need to meet the increasing local and regional sugar demand, and fossil fuel import substitution, cane expansion has potential negative impact on food security and biodiversity. However, this negative impact parallels the benefits related to cane cultivation. Cane biomass yield can be improved and sustained through the integrated use of various

practices reported in this study. Consequently this reduces the need to expand land acreage under cane while releasing land for use in food crop productivity. The high biomass returned to the ground sequesters carbon thereby offering the opportunity for sugarcane based farmers to earn extra income through the sale of carbon credits. Trickle down effects are expected to increase household income through the production and marketing of cane based biofuel and electricity.

These developments are expected to improve the farmers purchasing power, making households to be less dependent on the land and more food secure financially.

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